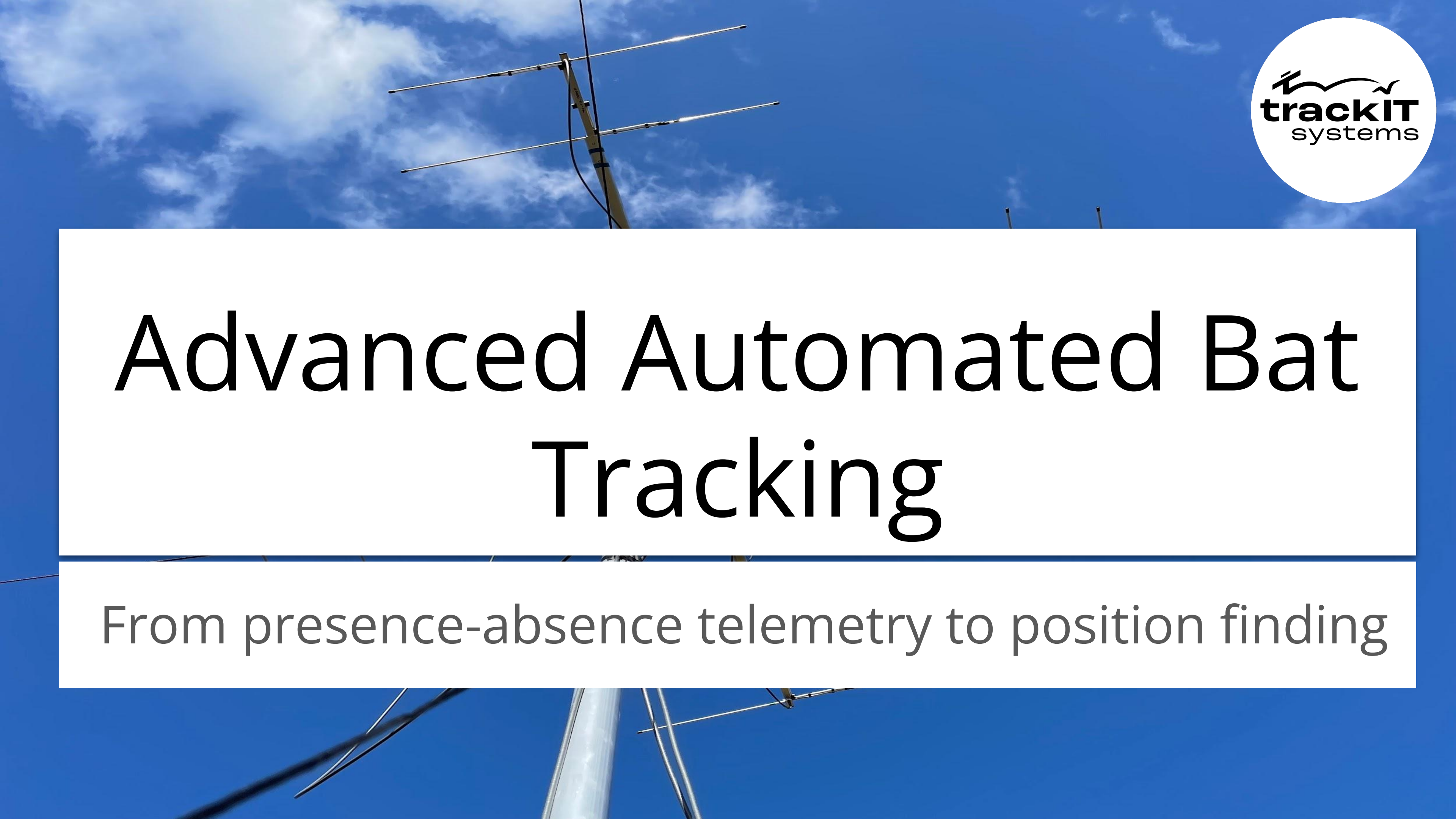
trackIT systems

Advanced Automated Bat Tracking

From presence-absence telemetry to position finding



Who we are | Founders

Patrick Lampe

PhD Computer Science

Hardware & Operations

Jonas Höchst

PhD Computer Science

Software & Technology

Jannis Gottwald

PhD Environmental Informatics

15 years of field experience

Practical Applicability & Vision

since 2019

Joined research efforts in automated radio telemetry and AI-enabled wildlife monitoring

2023

EXIST start-up grant at University of Marburg, Germany

2024

Independent operation, first employees and own facilities

Who we are | Team

Melina Morch

App Development

Christian Birk

Hardware Development

Tobias Petschinka

Nature Conservation

Dr. Artur Sterz

Research & Development

Dr. Daniel Knitter

(Spatial) Data Analysis

Caro Kordges

Sensor-Development & Bat Research

Arne Kärchner

Business Administration

Michael Fuchs

Machine Learning

2024

Distr@l grand for machine learning for passive acoustic monitoring

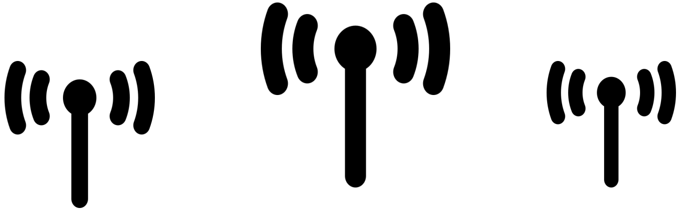
digitales.hessen DISTR@L

2025

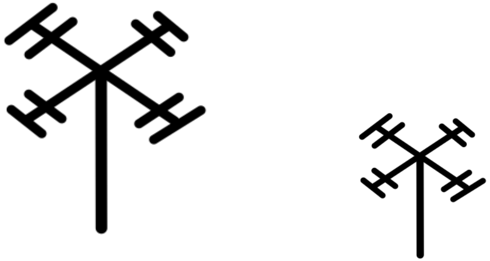
...

Introduction & State of the Art

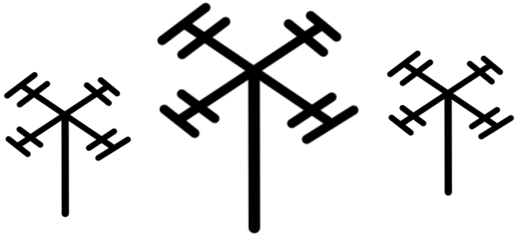
Manual Biangulation
~ 30 years



Presence-Absence telemetry
(since 2022)



Automated biangulation
(since 2019)

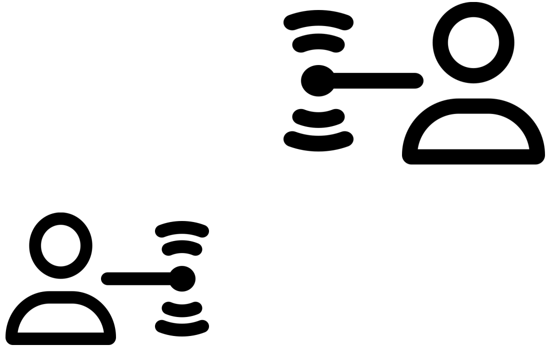


Improved position finding
(since 2024)

Manual Biangulation

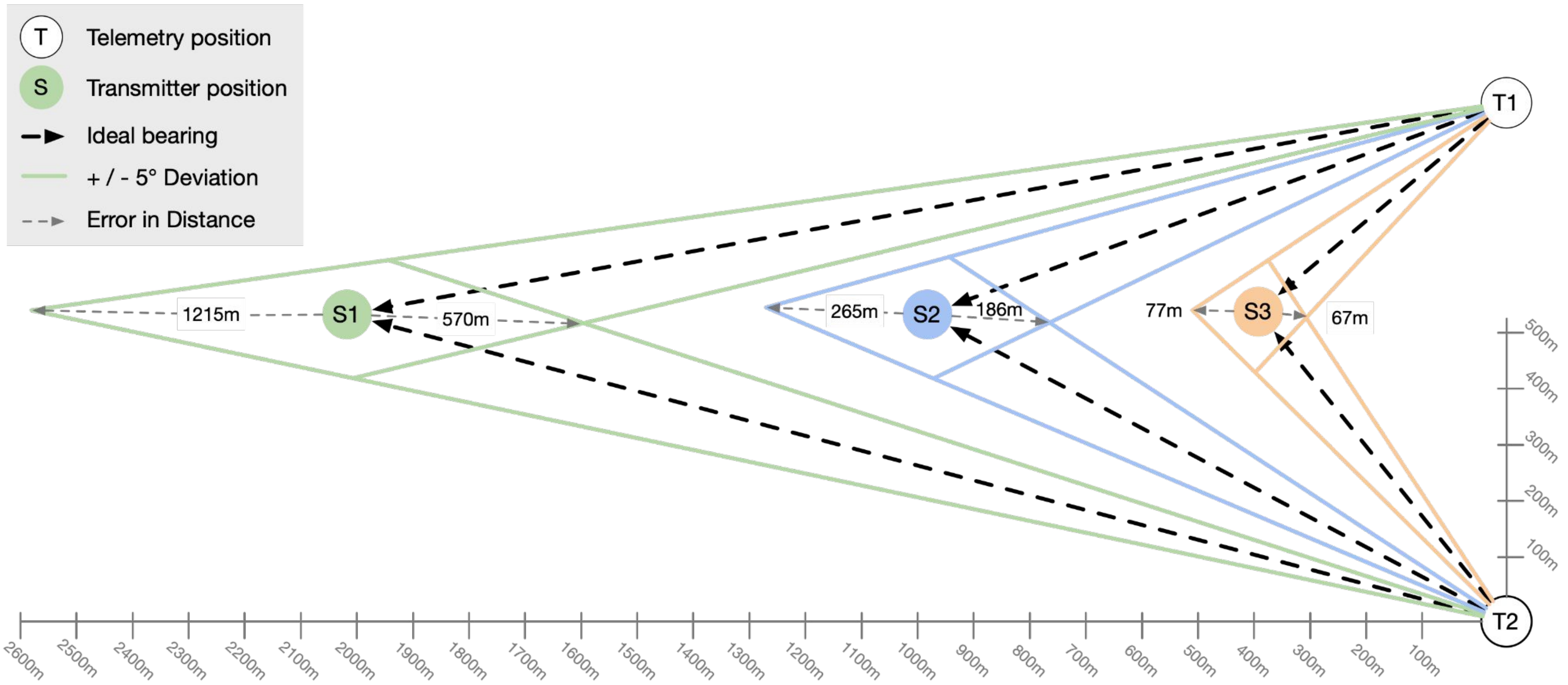
Manual Biangulation: Approach

- **Two** (or more) **directional receivers** tuned to a target frequency
- Recording of **location and bearing** at simultaneous points in time
- **Calculation of intersections**, oftentimes after the field season



Bearing measurements from two locations with hand receivers

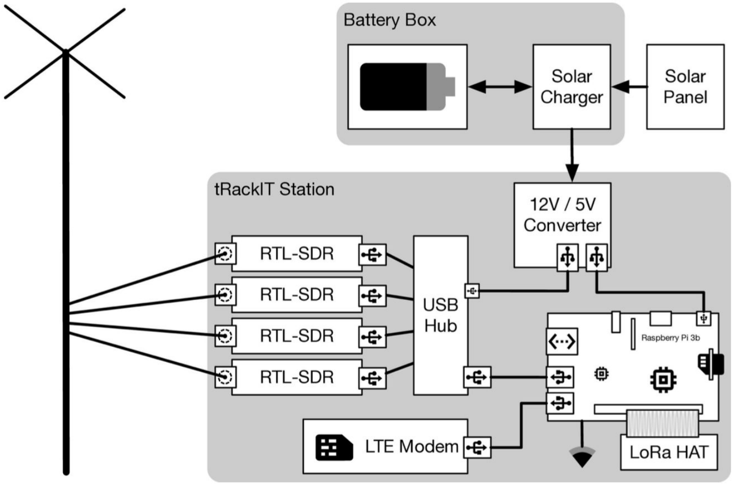
Manual Biangulation: Challenges



Automated Radio Telemetry: Foundation

Automated radio telemetry: Approach

- **Minicomputer** (Raspberry Pi)
- Self-sufficient **power supply** using batteries and solar panels
- Software-defined radio (SDR) for signal digitalization
- Algorithms for detecting **VHF signals** in a **300 (900) kHz** frequency band around **150.150 MHz** (configurable)



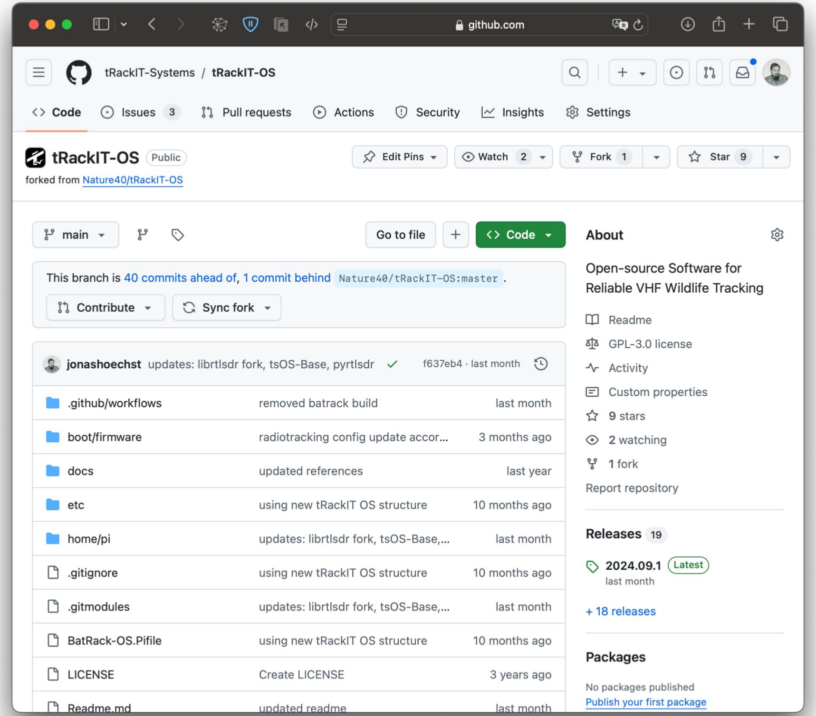
Hardware components of a trackIT station for VHF wildlife telemetry.

J. Höchst, J. Gottwald, P. Lampe, J. Zobel, T. Nauss, R. Steinmetz, and B. Freisleben, “tRackIT OS: Open-source Software for Reliable VHF Wildlife Tracking,” in 51. Jahrestagung der Gesellschaft für Informatik, Digitale Kulturen, INFORMATIK 2021, Berlin, Germany, 2021.

Automated radio telemetry: Software

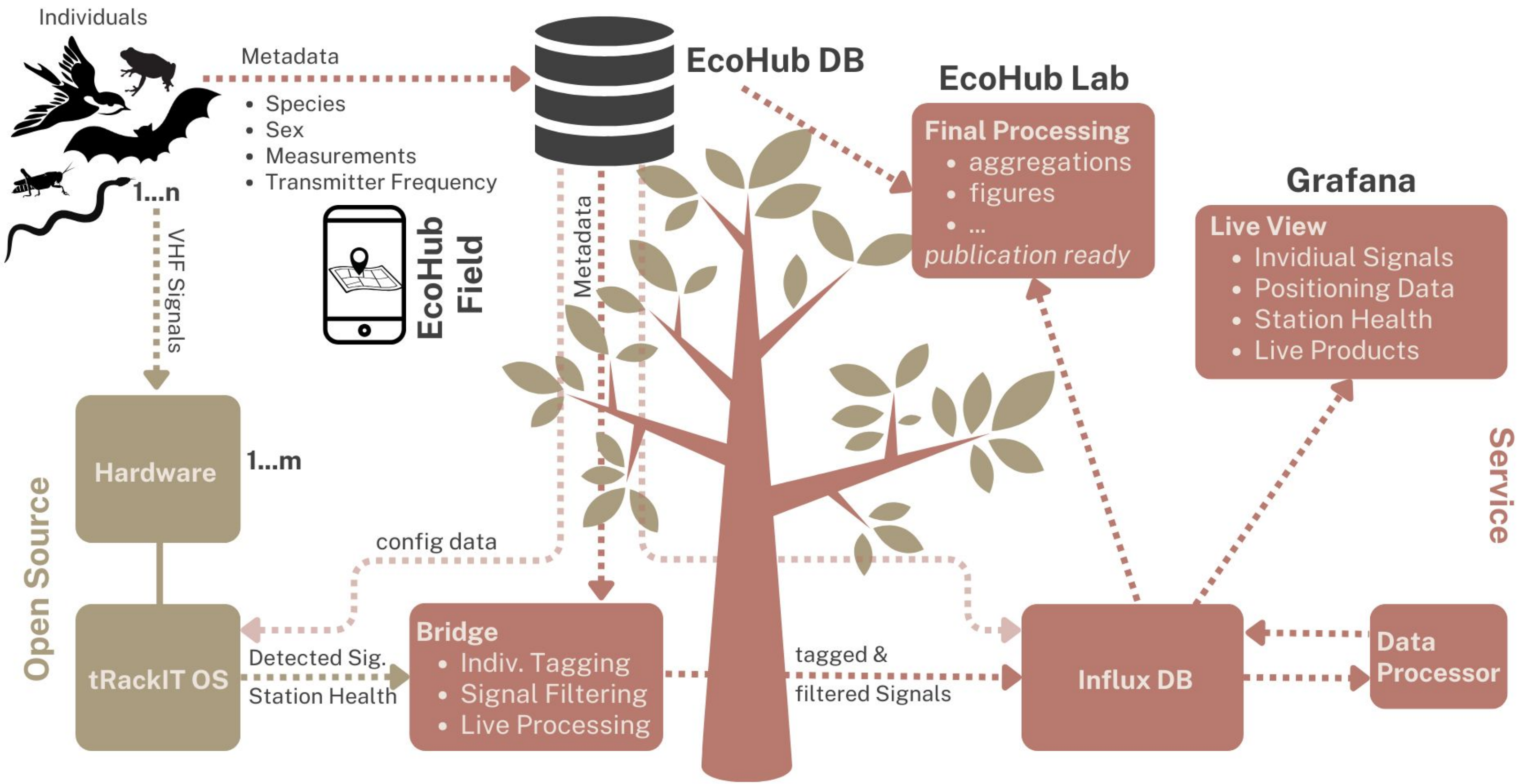
- **Open-Source Software** based on Linux
- Free Download, independent usage possible
- Based on Linux and **standard components**
- Configuration through a **small number** of standardised **files**

Installation: **Flashing** of the downloaded image to an SD card.

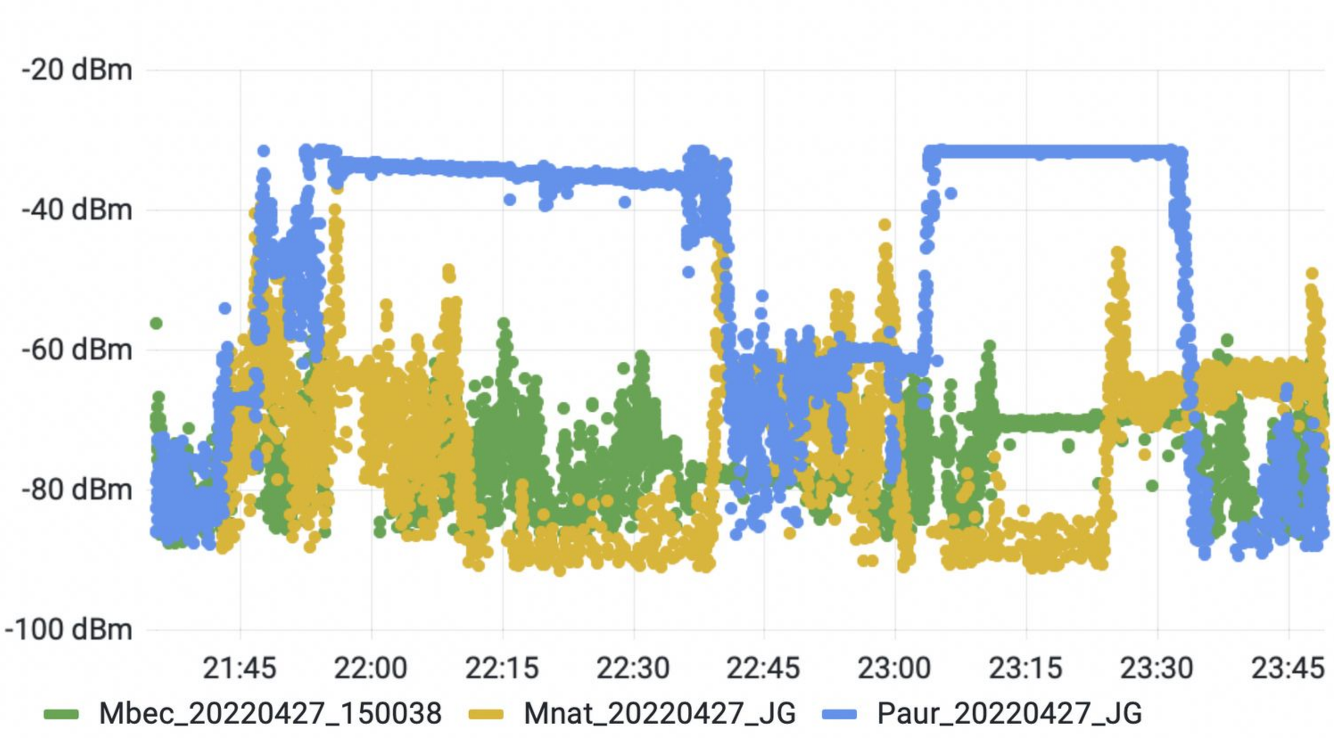


https://github.com/tRackIT-Systems/tRackIT-OS

Automated radio telemetry: The trackIT System



Automated radio telemetry: Live visualisation



Example for received signals strengths in a window of 2 hours

- Three individuals from different species (Myotis bechsteinii, Myotis nattereri, Plecotus auritus)
- > 7000 received data points per individual
- Activity individual can be inferred from signal strengths

Presence-absence telemetry

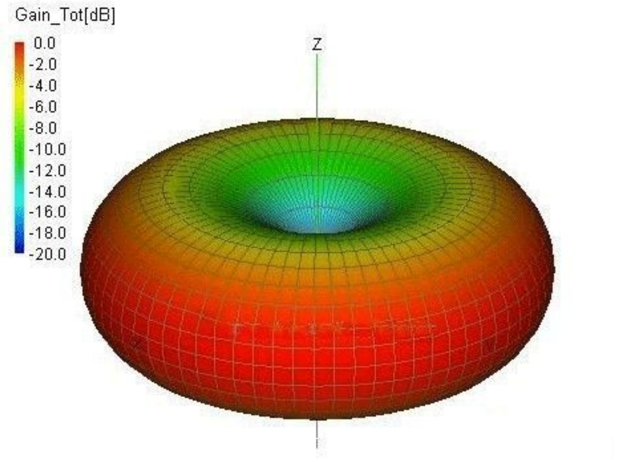
Presence-absence telemetry: Distance Estimation

Requirements

- **Decrease** in signal strength **with increased distance** between transmitter and receiver
- Signal strength from an **omnidirectional antenna** or combination of directional antennas

Use cases

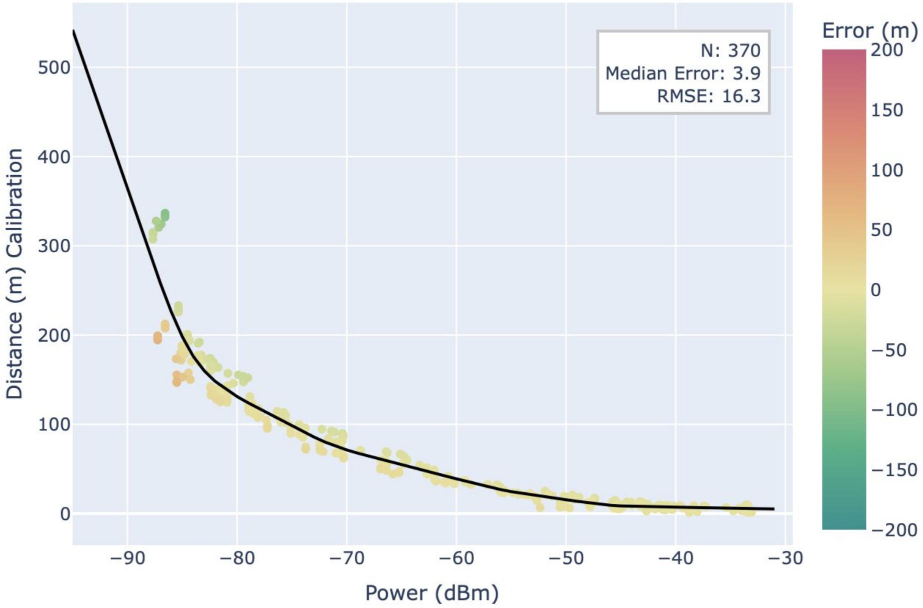
- Ideal in **construction**, e.g. in wind power, road construction
- Place stations at the planned locations



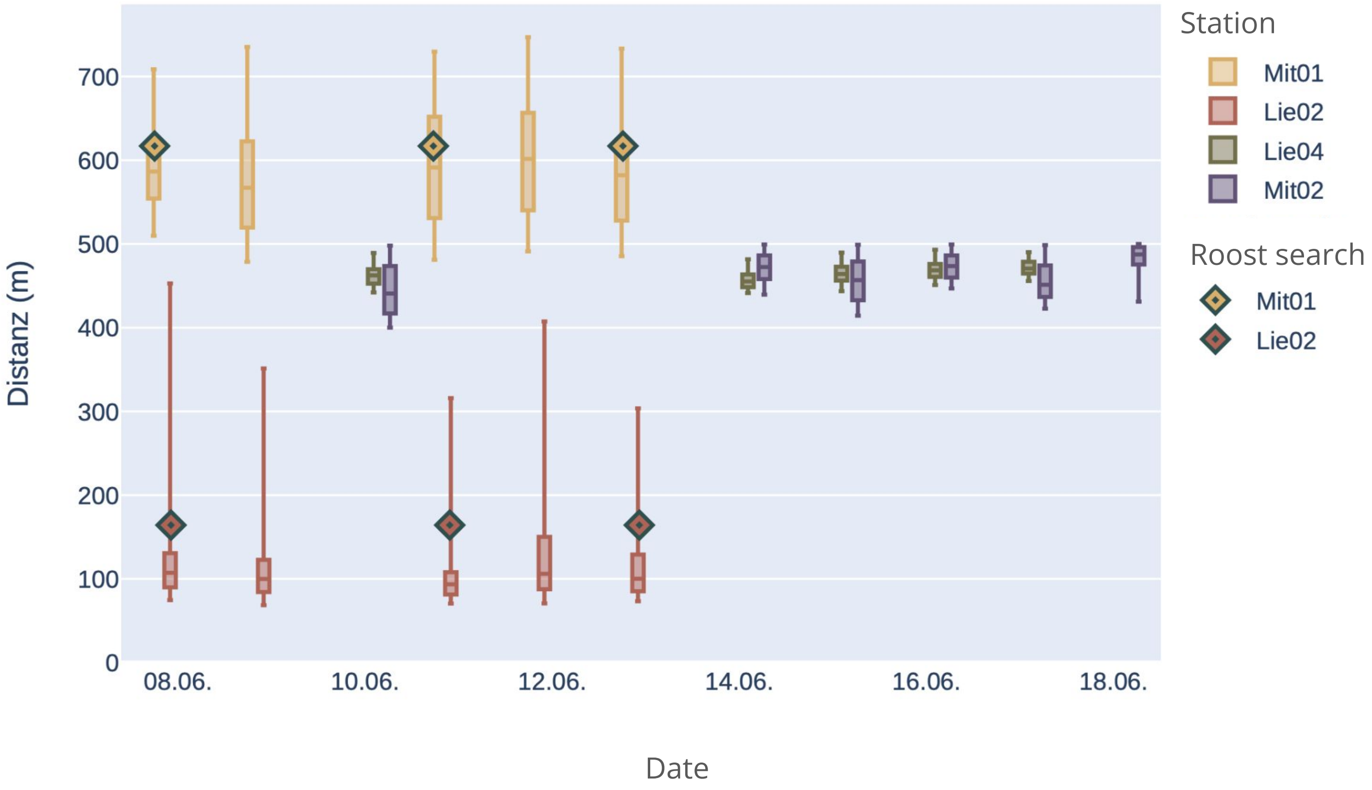
Gain in reception of a directional antenna to be used for presence-absence telemetry

Presence-absence telemetry: Calibration

- **Calibration walk** via GPS
- Measured **signal strength** and calculated **distance** are approximately exponentially decreasing
- **Configurable models:**
  - Exponential (physical) power-distance model
  - Generalized Additive Model (GAM)



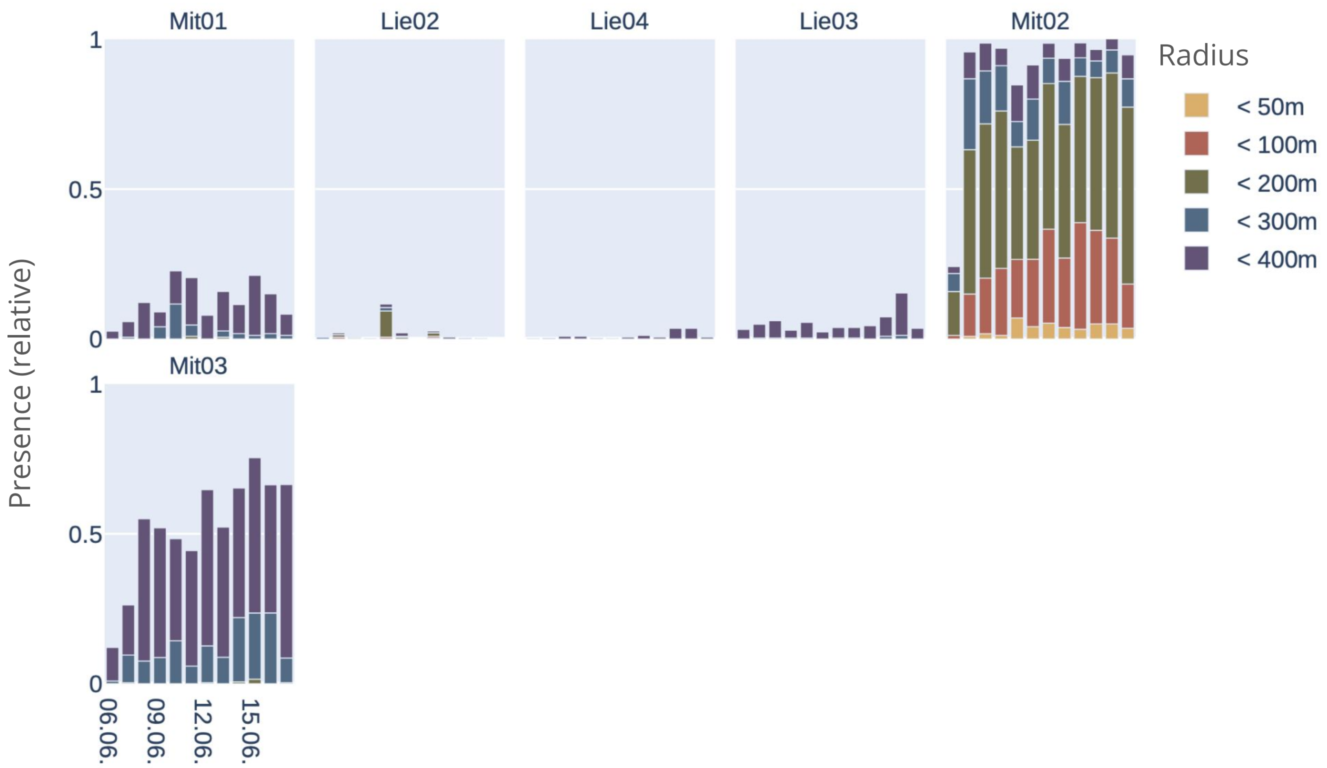
Distances during daytime: Roost usage



Daytime roost distance aggregation

- Individual used two different roosts in the 10 days of observation
- One roost was searched manually and found three times
- The second roost wasn't found through manual roost search

Distances during nighttime: Presence in radii



Nighttime roost distance localization

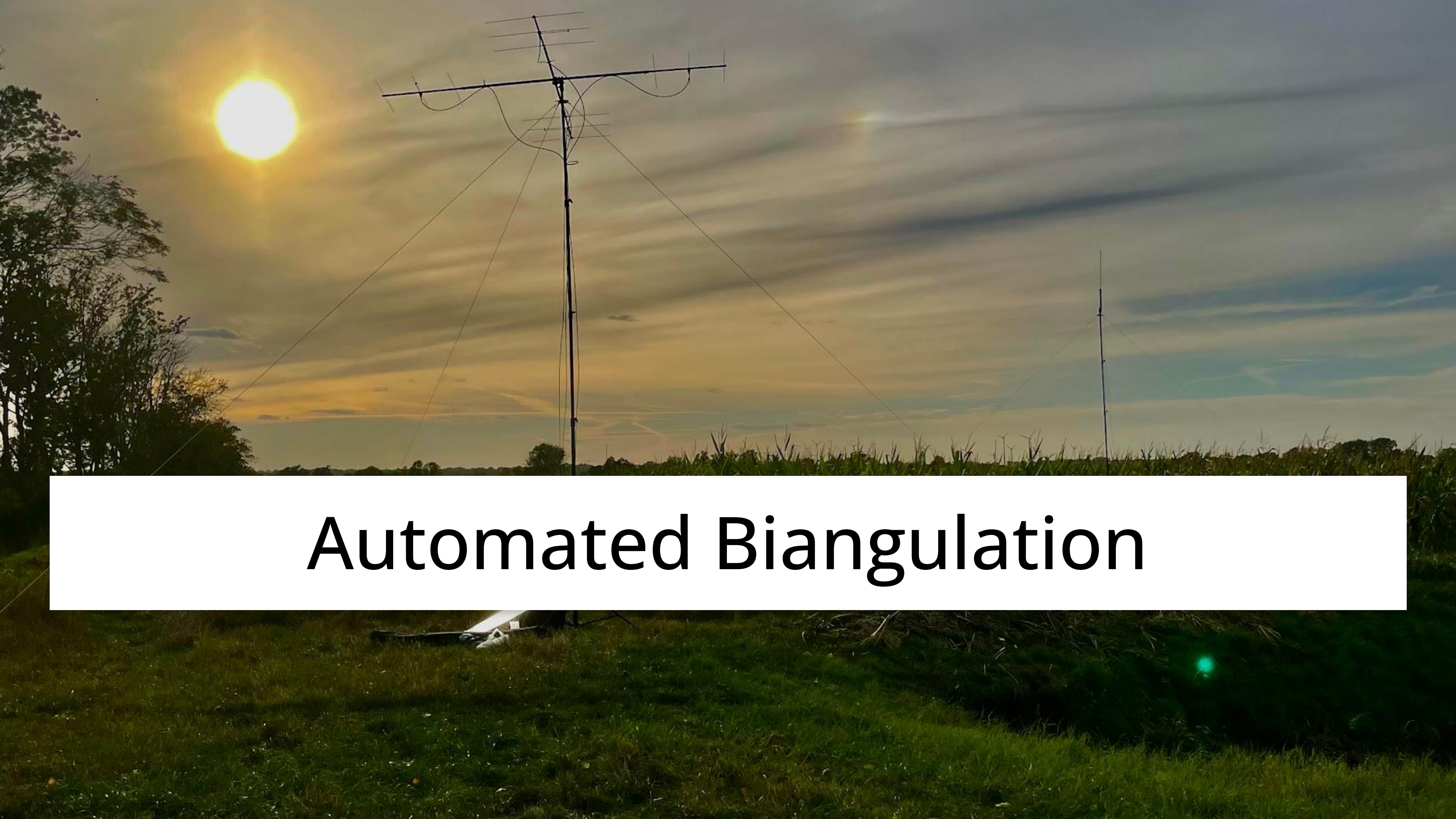
- Individual was near to station Mit02 and Mit03 for every of the observed nights
- Likely foraging grounds somewhere around / between Mit02 and Mit03

Distances during nighttime: Map radii plot

Nighttime roost distance map view

- Aggregated mean over multiple nights
- Foraging grounds around Mit02 and Mit03 with some shorter presences around Mit01, Lie02, Lie03

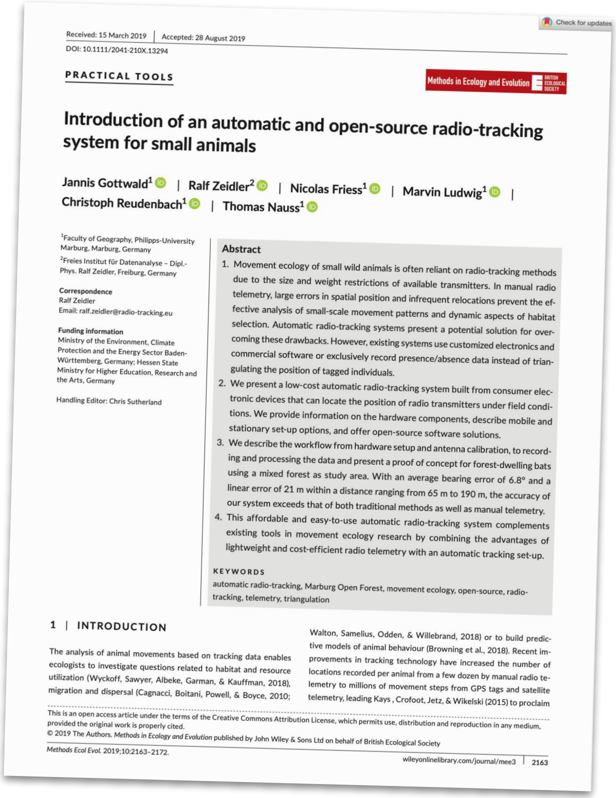
Automated Biangulation



Automated biangulation: State of the Art

Where do we come from?

- **Automated Biangulation**
  Bearing measurement through differences in signal strengths of neighboring antennas
- **Introduced 2019** by Gottwald & Zeidler et al. in Methods in Ecology and Evolution


Check for updates
Received: 15 March 2019 | Accepted: 28 August 2019
DOI: 10.1111/2041-210X.13294
PRACTICAL TOOLS
Methods in Ecology and Evolution

Introduction of an automatic and open-source radio-tracking system for small animals

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Ministry of the Environment, Climate Protection and the Energy Sector Baden-Württemberg, Germany; Hessen State Ministry for Higher Education, Research and the Arts, Germany

Handling Editor: Chris Sutherland

Abstract
1. Movement ecology of small wild animals is often reliant on radio-tracking methods due to the size and weight restrictions of available transmitters. In manual radio telemetry, large errors in spatial position and infrequent relocations prevent the effective analysis of small-scale movement patterns and dynamic aspects of habitat selection. Automatic radio-tracking systems present a potential solution for overcoming these drawbacks. However, existing systems use customized electronics and commercial software or exclusively record presence/absence data instead of triangulating the position of tagged individuals.
2. We present a low-cost automatic radio-tracking system built from consumer electronic devices that can locate the position of radio transmitters under field conditions. We provide information on the hardware components, describe mobile and stationary set-up options, and offer open-source software solutions.
3. We describe the workflow from hardware setup and antenna calibration, to recording and processing the data and present a proof of concept for forest-dwelling bats using a mixed forest as study area. With an average bearing error of 6.8° and a linear error of 21 m within a distance ranging from 65 m to 190 m, the accuracy of our system exceeds that of both traditional methods as well as manual telemetry.
4. This affordable and easy-to-use automatic radio-tracking system complements existing tools in movement ecology research by combining the advantages of lightweight and cost-efficient radio telemetry with an automatic tracking set-up.

KEYWORDS
automatic radio-tracking, Marburg Open Forest, movement ecology, open-source, radio-tracking, telemetry, triangulation

1 | INTRODUCTION

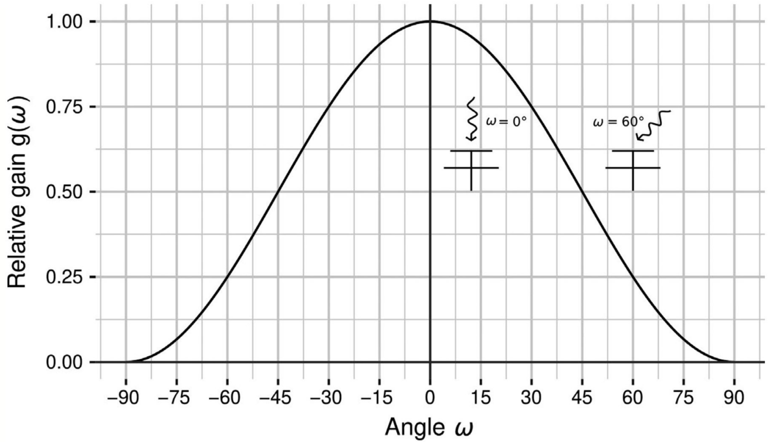
The analysis of animal movements based on tracking data enables ecologists to investigate questions related to habitat and resource utilization (Wyckoff, Sawyer, Albeke, Garman, & Kauffman, 2018), migration and dispersal (Cagnacci, Boitani, Powell, & Boyce, 2010; Walton, Samelius, Odden, & Willebrand, 2018) or to build predictive models of animal behaviour (Browning et al., 2018). Recent improvements in tracking technology have increased the number of locations recorded per animal from a few dozen by manual radio telemetry to millions of movement steps from GPS tags and satellite telemetry, leading Kays, Crofoot, Jetz, & Wikelski (2015) to proclaim

Gottwald, J., Zeidler, R., Friess, N., Ludwig, M., Reudenbach, C., & Nauss, T. (2019). Introduction of an automatic and open-source radio-tracking system for small animals. Methods in Ecology and Evolution, 10(12), 2163-2172.

Automated biangulation: Bearing calculation

Preconditions

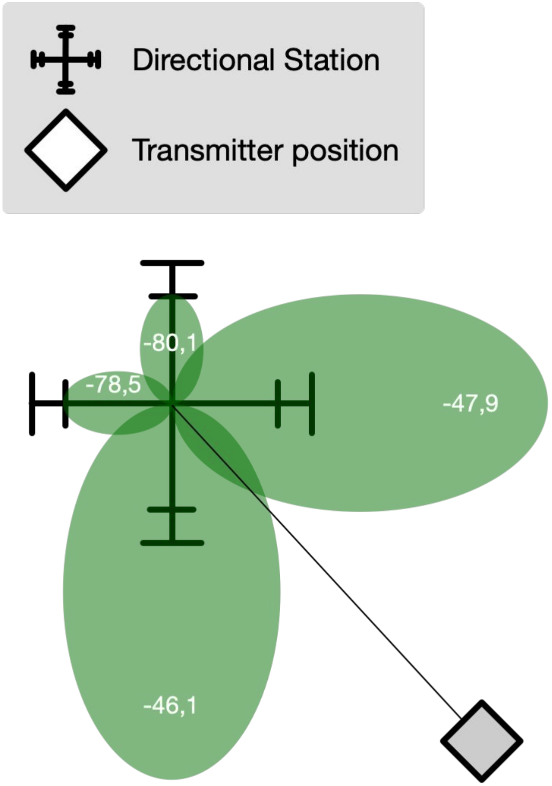
- **Directional antennas**: HB9CV, Yagi, ...
- Antennas with **fixed alignment**, maximum 90° to each other
- Reception of the transmitter on **at least two antennas** per station



The measured signal strength depends on the angle of the transmitter to the antenna.

Automated biangulation: Bearing example

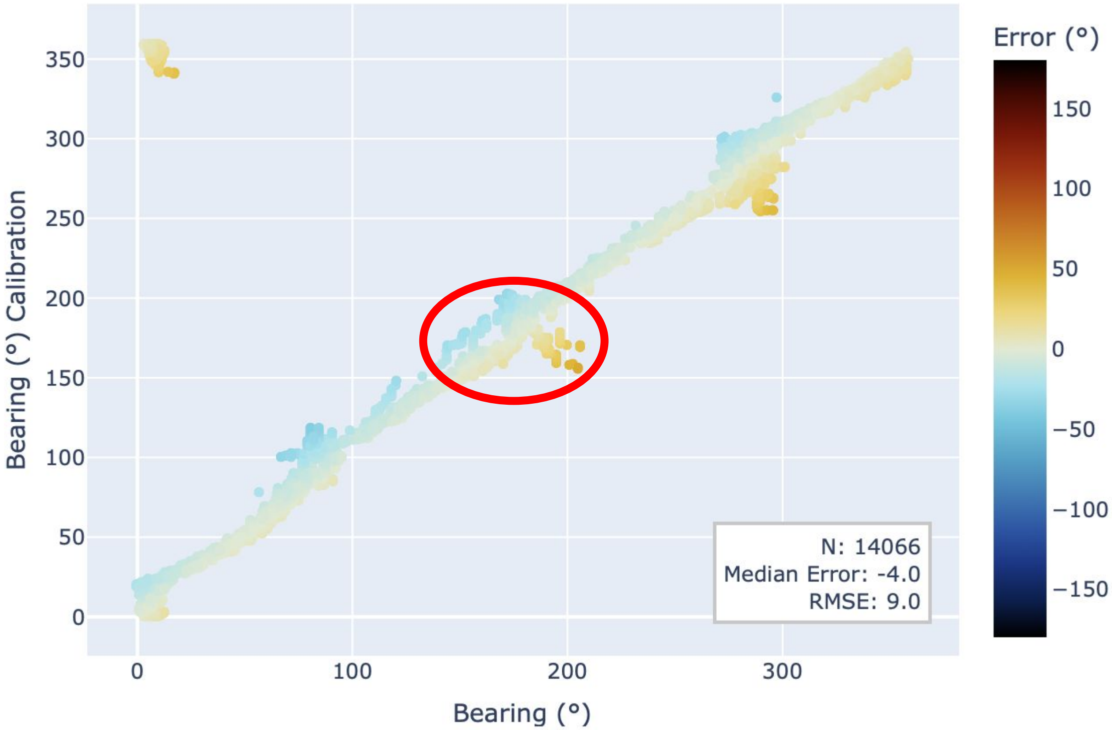
1. Identification of the strongest and neighboring second antenna
   -80,1 | **-47,9** | **-46,1** | -78,5
2. Calculation of the difference in signal strengths and normalization
   (47,9 - 46,1) / 28 = 0,064
3. Conversion of the difference value to an angle difference
   (90° - 90° * 0,064) / 2 = **42,12°**
4. Rotation to align the primary antenna
   180° - 42,12° = **137,88°**



Maximum gain difference: 28 dB

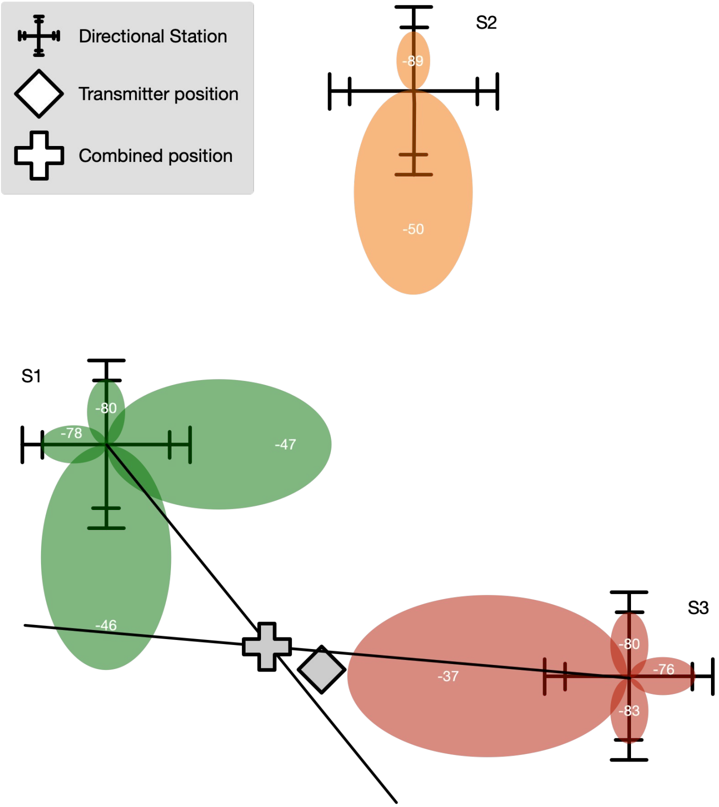
Automated biangulation: Challenges

- **Decision errors** with neighboring antennas => errors regularly at 0°, 90°, 180°, 270°
- Often faulty at **close range**, as all antennas receive very high signal strength
- Method provides **no quality metric** for the calculated angles



Automated biangulation: Position finding

- Position finding by means of the **intersection of the bearing lines** of two stations
- **Averaged position** for angles of more than 2 stations
- **Improvement possible** with the help of signal strength-distance models
  - Maximum distance of the intersection point in double distance estimation
    => Exclusion of unrealistic positions
  - Intersection points of more than 2 stations, weighting of the intersection points based on the estimated distances



Automated biangulation: Conclusion

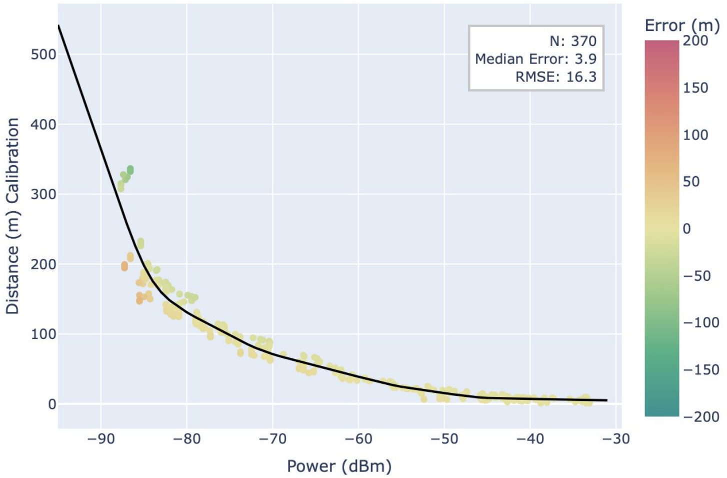
- **Easy to understand** procedure, analogous to manual positioning
- No results if not received on **at least two stations with two antennas**
- Based on **bearing**, no use of distance information

Automated Multilateration

Multilateration: Distance determination

Requirements

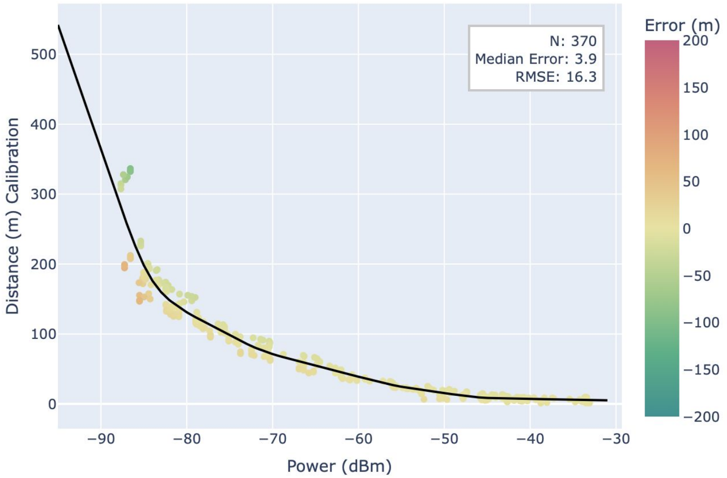
- **Decrease** in signal strength **with increased distance** between transmitter and receiver
- Signal strength from an **omnidirectional antenna** or combination of directional antennas
- Distances of **at least 3 stations**



The measured signal strength depends on the distance between the transmitter and receiver.

Multilateration: Calibration

- **Exponential power-distance model**: d = a * b^p
- **Generalized Additive Model (GAM)**: Combination of up to 20 terms to fit a convex curve

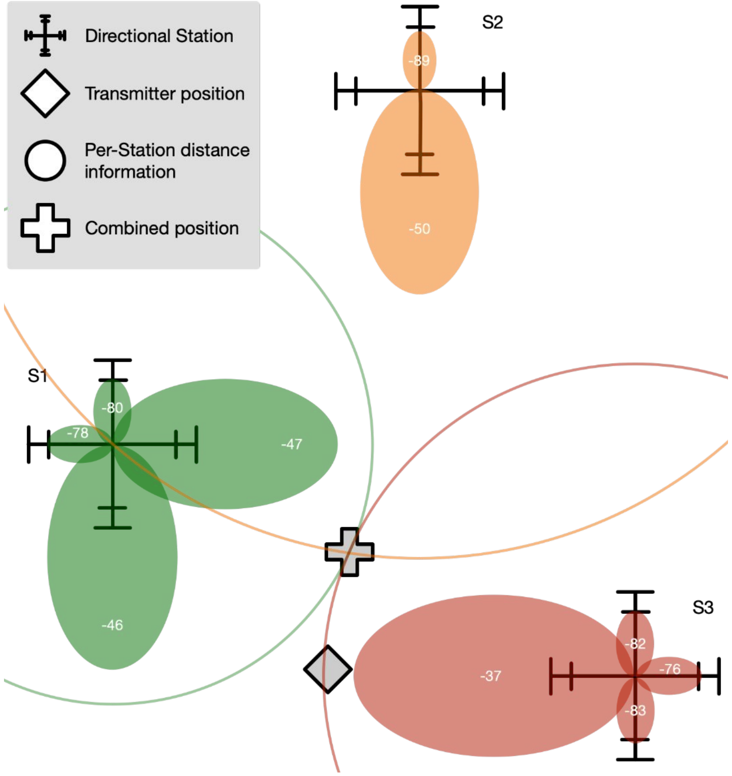


The measured signal strength depends on the distance between the transmitter and receiver.

Multilateration: Position finding

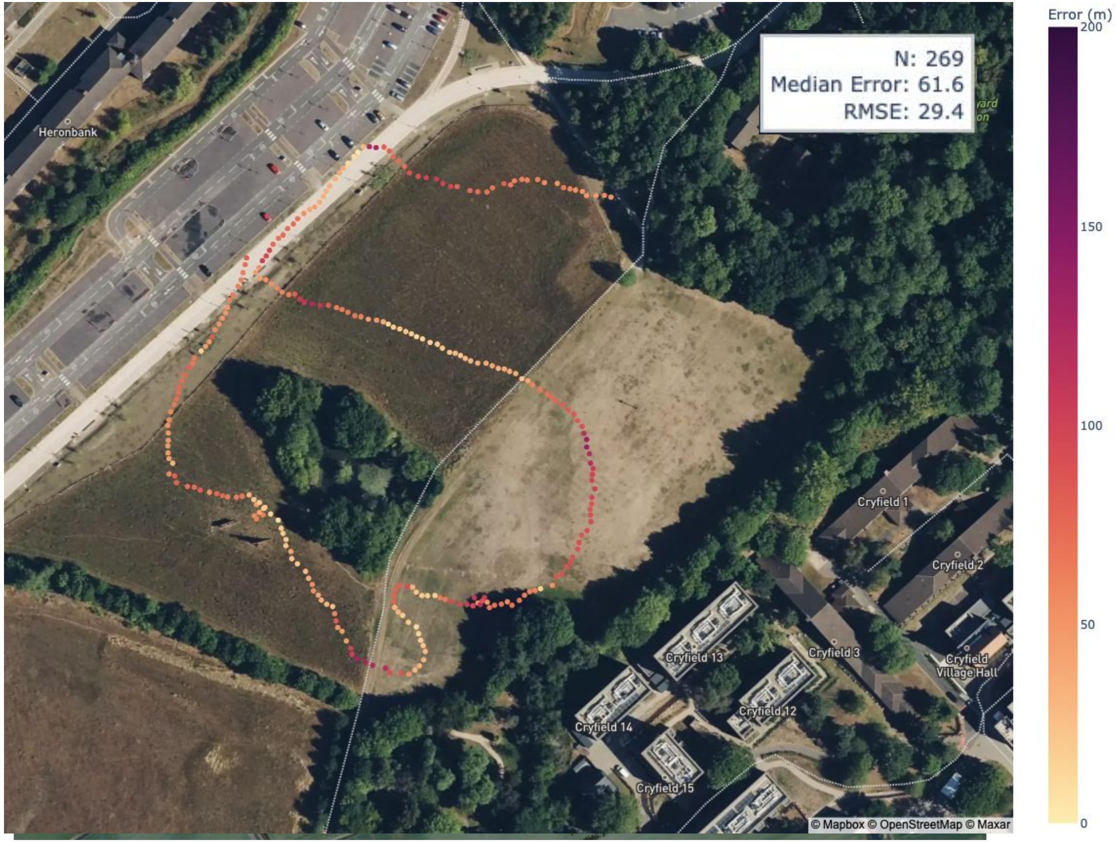
- **Distance calculation** according to calibrated models
- **Initial position**: Average of station positions weighted by distance

- Optimization by **minimizing the sum of the squared distance error**
  => Informed *trial and error* of points starting from the initial position



Automated Multilateration: Conclusion

- Position finding with **omnidirectional receives**
- Reception on **at least 3 stations** necessary
- Only **based on distance information**
- **Long runtimes**, as computationally complex optimization per point necessary



Antennabeam Position finding

Antennabeam: Introduction

Requirements

- Each directional receiver has a **maximum reception range** and a gain in its **directional characteristic**.

Basic idea

- For each receiver, a point is created in the **alignment of the antenna** and **half of the reception range**.
- Points of several antennas of a **station are weighted** and averaged according to signal strength.

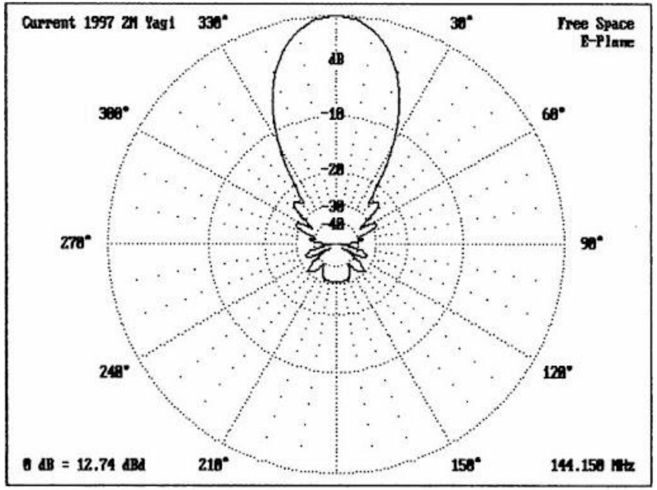
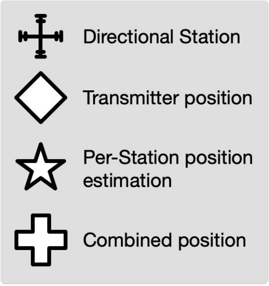


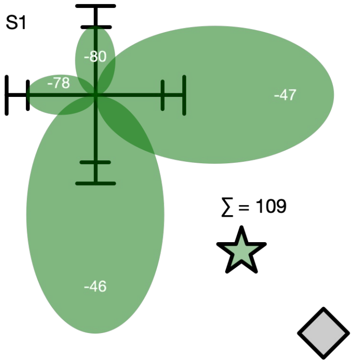
FIG. 1a.

Antennabeam: Position finding per station

Station S1 Coordinates: 100, 470

- Received on all 4 antennas
  -80 | -47 | -46 | -78
- Normalization:
  10 | 43 | 44 | 12 **∑ = 109**
- Offset X = (43 - 12) / 109 * 500 = **142 m**
- Offset Y = (44 - 10) / 109 * 500 = **155 m**
- Position for S1:
  X: 100 + 142 = **242**
  Y: 470 + 155 = **625**



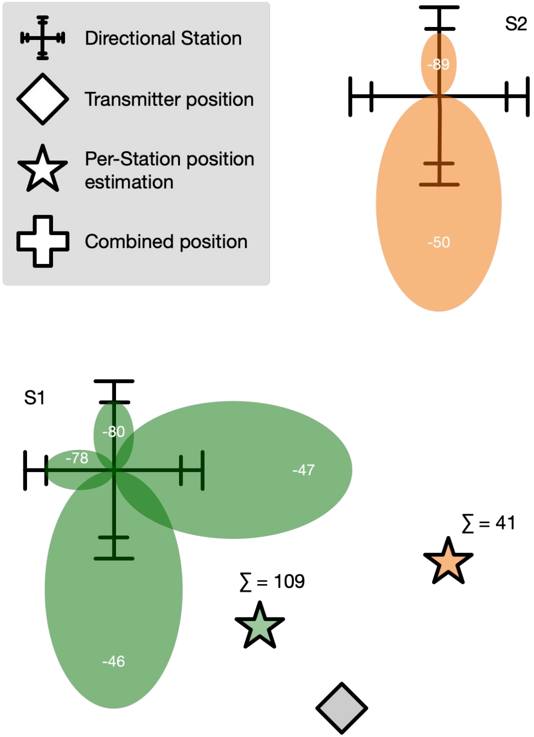


Gain normalization: 90 dB, detection range: 1000m

Antennabeam: Position finding per station

Station S2 Coordinates: 438, 82

- Received on 2 antennas
  -89 | - | -50 | -
- Normalization:
  1 | 0 | 40 | 0 **∑ = 41**
- Offset X = (0 - 0) / 41 * 500 = **0 m**
- Offset Y = (40 - 1) / 41 * 500 = **476 m**
- Position for S2:
  X: 438 + 0 = **438**
  Y: 82 + 476 = **558**

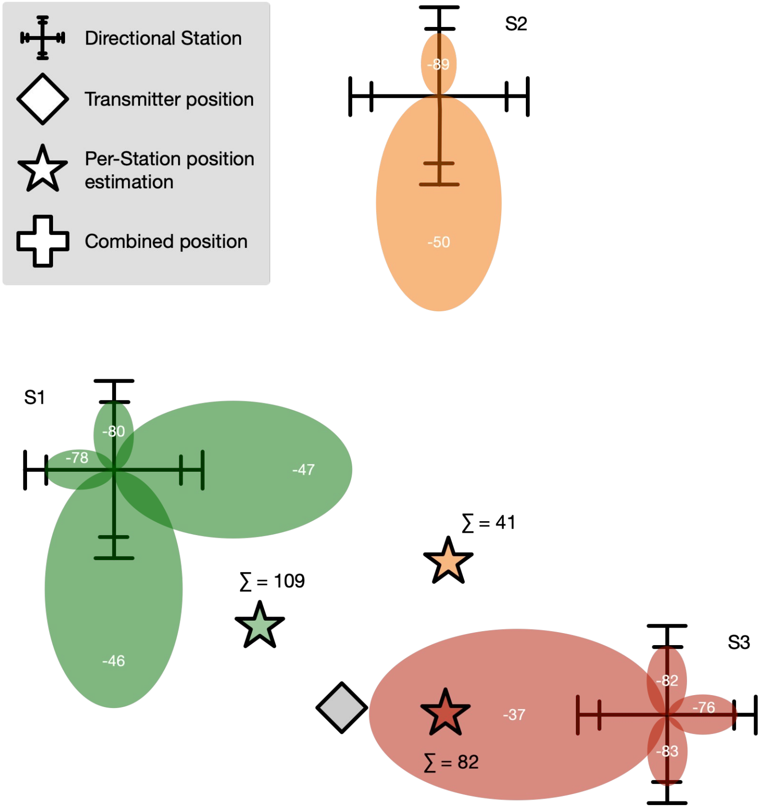


Gain normalization: 90 dB, detection range: 1000m

Antennabeam: Position finding per station

Station S3 Coordinates: 673, 722

- Received on 4 antennas
  -82 | -76 | -83 | -37
- Normalization:
  8 | 14 | 7 | 53 **∑ = 82**
- Offset X = (14 - 53) / 82 * 500 = **-238 m**
- Offset Y = (7 - 8) / 82 * 500 = **-6 m**
- Position for S3:
  X: 673 - 238 = **435**
  Y: 722 - 6 = **716**

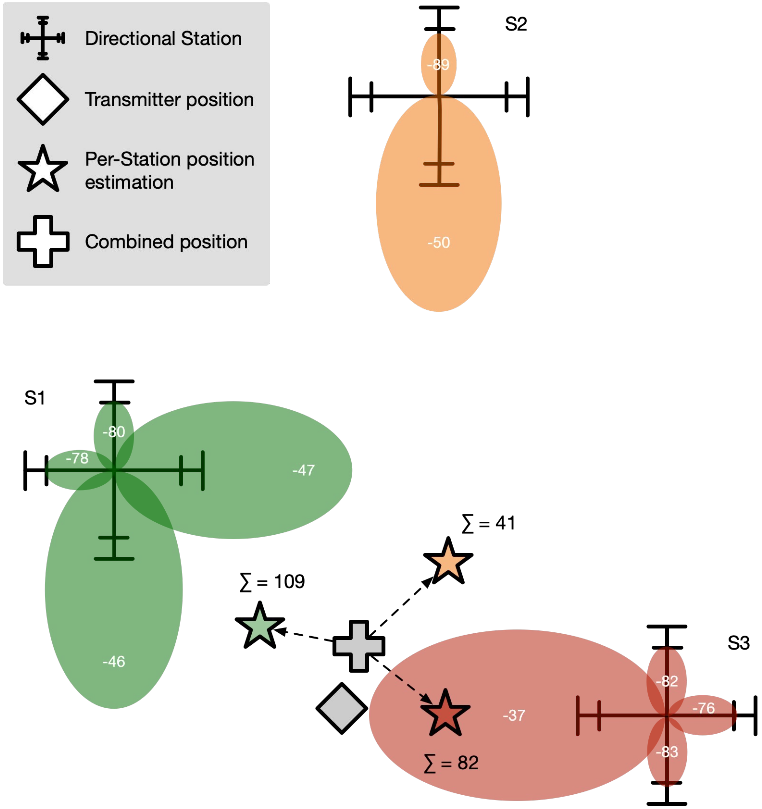


Gain normalization: 90 dB, detection range: 1000m

Antennabeam: Position finding

Positions

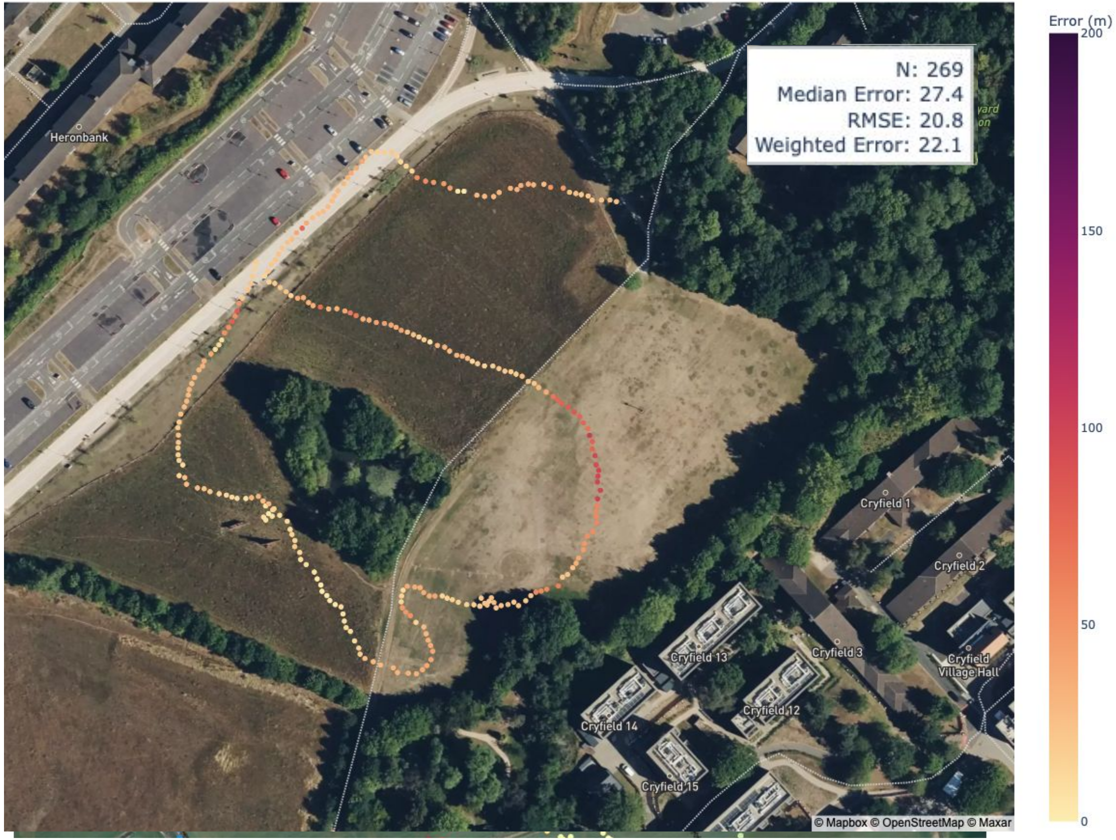
- Weight sum: 109 + 41 + 82 = 232
- Weighted average for positions:
  (242 * 109 + 438 * 41 + 435 * 82) / 232 = **345**
  (625 * 109 + 558 * 41 + 716 * 82) / 232 = **645**



Gain normalization: 90 dB, detection range: 1000m

Antennabeam: Conclusion

- Disadvantage: **Rather difficult to understand**, intuitive understanding develops gradually
- Inclusion of **distance and direction** per station
- **Quality metric** for each position found (weights)
- **High number** of found positions, even in the peripheral areas



Antennabeam Hands-On

Test area near the conference


trackIT
systems
Catch me
if you can
Tobias Petschinka
trackIT Systems
Warwick Arts Centre

Projects 2024

Meadow breeder protection
Oystercatcher, Eurasian curlew, lapwing, black-tailed godwit, redshank. Various areas from the North Sea to Bavaria

Animal release projects and exposure studies with songbirds
Tree sparrow, robin, tits...
Dupont's lark in Spain

Bats in intervention procedures
> 500 individuals from 15 species since the beginning of 2023

Relocation experiment with Snakes
Smooth snake, grass snake, adder

Hedgehog, dormouse, hamster, pond turtle...

More information on our website

Thank you!